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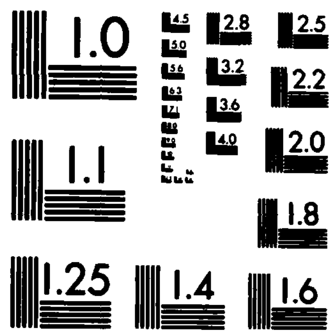

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COREBREAKER AND BLOCKAGE EVALUATION TEST IN THE AEDC AEROTHERMAL MACH NUMBER 4 WIND TUNNEL

D. B. Carver

Calspan Field Services, Inc.

May 1982

Final Report for Period April 7, 1982.

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APPROVAL STATEMENT

This report has been reviewed and approved.

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Approved for publication:

FOR THE COMMANDER

John M. Rampy

JOHN M. RAMPY, Director
Aerospace Flight Dynamics Test
Deputy for Operations

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REPORT DOCUMENTATION PAGE

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corebreaker
model blockage
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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Tests were performed in the AEDC Mach number 4 wind tunnel to determine corebreaker effectiveness for reducing pressure fluctuations in the stilling chamber. Basic blockage data were also obtained using blunt and conical models to determine maximum model size for the facility. Another test objective was to confirm that the upper operating temperature limit of 1900°R could be achieved. The stilling chamber pressure ranged from 15 to 100 psia, with temperatures from ambient to 1900°R.

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NOMENCLATURE

A_M	Model frontal area, in.^{2}
AREA	Geometric or effective nozzle throat or valve cross sectional area, in.^{2}
A_T	Free jet nozzle exit area, 490.9 sq. in.
CONFIG	Blockage model configuration code (see Fig. 4)
CP_n, CP_	Dynamic pressure ratio, $DPWC_n/PWC_n$
DEWPT	Stilling chamber air dewpoint, referenced to atmospheric pressure, °F
$DPWC_n$, DPWC_	RMS value of the dynamic pressure measurement, mv or psi
MACH, M	Average test section Mach number
MFRAC	Ratio of the mass flow through the primary or bypass line to the total mass flow rate
MODEL	Blockage model identification (see Fig. 4)
MU	Free-stream viscosity, lb_f-sec/ft^2
$\dot{m}$	Mass flow rate, lbm/sec
P	Free-stream static pressure, psia
PB	Model base pressure, psia
PD_n, PD_( )	Tunnel wall diffuser surface static pressure for n = 1, 2, 3, 4 and 6. Diffuser pitot pressure for n = 5. Tunnel coordinate, X inside ( ), psia
PE_n, PE_ ( )	Nozzle exit static pressure at the n^{th} orifice, radial position, ς inside ( ), psia

PF	Cavity pressure from an orifice located at the flange between the aerothermal nozzle and the 50 in.-diam test section, psia
PEAVG	Average of the four nozzle exit static pressures, psia
PHB1	Air pressure measured in the line just downstream of heater HB1, psia
POSITION	Blockage model position as shown in Fig. 5
PT, PT_	Mach 4 nozzle stilling chamber pressure, psia
PTC 1, 2	Mach 10 nozzle stilling chamber pressure, psia
PT2	Computed pressure downstream of a normal shock, psia
PWC_n, PWC_	Mixing chamber wall pressure, PWC4 = PT is a direct measurement; PWC1, PWC2, PWC3 are computed by $PWC_n = PWC4 + PWC_{n4}$
$PWC_{n,m}$, PWC__	Pressure differentials in the mixing chamber, $PWC_{n,m} = PWC_n - PWC_m$; PWC14, 24, 34 are direct transducer measurements; PWC23 computed as PWC23 = PWC24 - PWC34, psi
Q	Free-stream dynamic pressure, psia
RE	Free-stream Reynolds number, per foot
RHO	Free-stream density, slug/ft^3
R_T, R	Radius, in.
RUN NO.	Data set identification number
T	Free-stream static temperature, °R
TD_n, TD_	Bypass duct line exterior surface temperatures: TD1, TD2 at 7 in. from mixer section located on the operating and nonoperating sides of the tunnel, respectively. TD3 at 6 ft from mixer section on operating side, °R
TF	Cavity air temperature at flange between the aerothermal nozzle and the 50-in. diameter test section, °R

THB1	Air temperature measured in the line just downstream of heater HB1, °R
TPPKG	Temperature within sector mounted Tunnel C pressure package, °R
TRF	Mach 4 throat flange exterior surface temperature, at a point ≈ 1.5 in. downstream of mixer section, °R
TRH	Mach 4 throat housing exterior surface temperature, at a point ≈ 25 in. downstream of mixer section, °R
TROLL	Temperature inside sector roll mechanism, °R
TSECTOR	Temperature inside sector pitch mechanism, °R
TT	Mach 4 nozzle stilling chamber temperature, average value, °R
TT_n, $TT_{(\ ,\ )}$	Stilling chamber temperature of the nth probe, numbers in ( ) below are radius and angular locations per Fig. 6, °R
TTC_n, $TTC_{(\ )}$	Mach 10 nozzle stilling chamber temperature of the n^{th} probe, letters in ( ) below are the permanent letter identification of these probes, °R
TV1, TV2	Relief valve outside surface temperature, valves 1 and 2, located on the operating and nonoperating sides of the tunnel, respectively, °R
TWC_n, $TWC\_$	Mixing chamber temperatures at the n^{th} location (see Fig. 7), °R
V	Free-stream velocity, ft/sec
X	Tunnel axial coordinate referenced to the midpoint between the test section windows (see Fig. 8), in.
¢	Tunnel radial angle, zero on top of tunnel and positive counter-clockwise looking upstream, deg

SUBSCRIPTS/POSTSCRIPTS

P	Primary measurement
R	Redundant measurement

1.0 INTRODUCTION

The work reported herein was performed at the Arnold Engineering Development Center (AEDC), Air Force Systems Command (AFSC), at the request of AEDC, Office of Aerospace Flight Dynamics Test (DOF). The Air Force Program Element number was 65807F, the Control Number was 9T03, and the Air Force project managers were Lt. Larry M. Davis and Lt. Mary Swillum, AEDC/DOFO. The results were obtained by Calspan Field Services, Inc./AEDC Division, operating contractor for the Aerospace Flight Dynamics testing effort at the AEDC, AFSC, Arnold Air Force Station, Tennessee. The tests were performed in the von Karman Gas Dynamics Facility (VKF), Hypersonic Tunnel C - Mach number 4 configuration, under AEDC Project Number C115VC on April 7, 1982.

Previous tests (Refs. 1 and 2) had shown severe vibrations in the tunnel mixing chamber with the tunnel operating in what is called the "Series Heater Circuit". These tests resulted in screen damage in the mixing chamber. To alleviate this problem a "corebreaker" was designed and installed at the mixing chamber entrance for the purpose of breaking up the core, broadening the fluctuation frequency spectrum, and causing an amplitude reduction in the low frequency fluctuations that were probably responsible for the screen damage.

The present test objectives were: (1) evaluation of a corebreaker to determine its effectiveness for reducing pressure fluctuations in the mixing chamber, (2) definition of maximum model size by conducting a blockage study with blunt and conical models, and (3) verification of test unit operation at temperatures higher than previously tested (1900°R as compared to the previous maximum of 1660°R).

The tests were performed over the entire operating range for the "Series Heater Circuit" Aerothermal Mach number 4 wind tunnel which corresponds to stilling chamber pressures from 15 to 100 psia at stilling chamber temperatures from near ambient to 1900°R. The blockage data were obtained using blunt and 30-deg half angle conical models with diameters up to one-half the free-jet exit diameter. Stilling chamber pressures for the blockage data were from 17 to 58 psia, with the majority of the blockage results obtained at 38 psia.

The primary instrumentation for the corebreaker evaluation was the dynamic pressure measurements in the mixing chamber. Instrumentation for blockage monitoring consisted of: shadowgraph pictures, nozzle exit pressures, model base pressure, and various wall pressures along the test section and the diffuser. Additional test instrumentation included numerous thermocouples for monitoring various components of the Aerothermal test unit and circuit air temperatures.

A summary of the test data transmitted to the sponsor (DOFO) is presented in Table 1.

Inquiries to obtain copies of the test results should be directed to AEDC/DOFO, Arnold Air force Station, TN 37389. A microfilm record has been retained in the VKF at AEDC.

2.0 APPARATUS

2.1 TEST FACILITY

The Mach 4 Aerothermal Tunnel is a closed-circuit, high temperature, supersonic free-jet wind tunnel with an axisymmetric contoured nozzle and a 25 in.-diam nozzle exit, Fig. 1. This tunnel utilizes parts of the Tunnel C circuit (the electric air heater, the Tunnel C test section and injection system) and operates continuously over a range of pressures from nominally 15 psia at a minimum stagnation temperature of 710°R to 180 psia at a maximum temperature of 1570°R. Using the normal Tunnel C Mach 10 circuit (Series Heater Circuit), the Aerothermal Mach 4 nozzle operates at a maximum pressure and temperature of 100 psia and 1900°R, respectively. The air temperatures and pressures are normally achieved by mixing high temperature air (up to 2250°R) from the primary flow discharged from the electric heater with the bypass air flow (at 1440°R) from the natural gas-fired heater. The primary and the bypass air flows discharge into a mixing chamber just upstream of the Aerothermal Tunnel stilling chamber. The entire Aerothermal nozzle insert (the mixing chamber, throat and nozzle sections) is water cooled by integral, external water jackets. Since the test unit utilizes the Tunnel C model injection system, it allows for the removal of the model from the test section while the free-jet tunnel remains in operation. A description of the Tunnel C equipment may be found in Ref. 3.

2.2 TUNNEL CIRCUIT

The "Series Heater Circuit" was used for the present test and is depicted schematically in Fig. 2. Nine stages of compression are used to supply the necessary pressure ratio and mass flow requirements, with the supply passing sequentially through the gas-fired heater (HB-1). Valve 254, the electric heater (HB-3), Mach 10 stilling chamber and throat, and into the Aerothermal mixing chamber. The flow leaves the mixing chamber and passes through the Mach 4 throat and nozzle before the free-jet exits into the Tunnel C test section and the flow returns to the compressor inlet.

The dashed lines in Fig. 2 represent portions of the circuit that are not used for the "Series Heater Circuit" and are normally sealed off using valves 454 and 554. For the present test Valve 554 was removed and the lines were capped.

2.3 TEST ARTICLES

The corebreaker (Fig. 3) consists of a 2.5-inch base diameter conical shape that is supported by six struts and included as a permanent part of a thermal shield located at the entrance to the Aerothermal Mixing Chamber. Positioning of the corebreaker at this location has the effect of "spreading and breaking up" the high energy core that exits from the Mach number 10 throat.

Two basic model shapes were used for the blockage study: 30-deg half-angle cone and "flat face" disks. The cone model was assembled from several cone segments, making it possible to vary the base diameter from 7.9 to 12.5 in. These same segments were mounted individually as flat-face disk models using a nut and bolt attachment for simplicity. Model details are given in Fig. 4 and an installation sketch is presented in Fig. 5. The cone model was run in one position (cone apex located two inches aft of nozzle exit) and the flat-face model was run at 6-inches and 16-inches aft of the nozzle exit with the majority of the results obtained at the 6-inch position.

2.4 TEST INSTRUMENTATION

The measuring devices, recording equipment, and calibration methods for all measured parameters are listed in Table 2 along with the estimated uncertainties. Instrumentation locations are illustrated in Figs. 6, 7 and 8, corresponding to total temperature probes, Aerothermal Mixer Section and Test Section/Diffuser pressure measurements.

Thermocouple probe positions used during the present test are shown in Fig. 6 for the Mach-10 and Mach-4 stilling chamber instrument rings. Additional probes are available but only those shown were recorded.

Figure 7 is a cross section of the mixing chamber showing the location of all instrumentation in the region. Six thermocouples (TWC1 - TWC6) were tacked to the downstream section of the first baffle to monitor the temperature gradient along this baffle and also to indicate the thermal uniformity of the airstream in the mixer. Seven additional thermocouples (TWC7 - TWC13) were located at various points on either side of the insulation between the inner and outer shell of the mixer. At four points along the mixer, dynamic pressure levels were recorded. The dynamic pressure transducers were located in water-cooled units mounted outside of the mixer section and were connected to the inner surface by straight tubes (Fig. 7b), 0.25-inch inside diam by 9-inches long. This ported type of installation gave a measured signal that, based on calibrations, was approximately one-half that of flush-mounted transducers. The pressure drop was measured between the first three points and the stilling chamber (point 4) using ordinary differential pressure transducers, with long lines leading to the transducers which eliminated pressure fluctuations.

Test section/diffuser instrumentation locations are shown in Fig. 8. Four static pressure orifices (Fig. 8a) were flush mounted near the nozzle exit. The cavity air pressure and temperature were measured at the test section flange as indicated by PF and TF in Fig. 8b. The test section diffuser was instrumented with five wall static orifices (PD1 - PD4 and PD6) and one pitot probe (PD5); the pitot extended 12 inches from the wall.

Positive proof of the flow breakdown (blockage) was provided by shadowgraph pictures recorded thru the tunnel standard single-pass optical flow visualization system. Figure 9 gives a typical picture sequence (2-4 sec intervals) for two cases: no blockage and intermittent blockage. Partial loss of flow is clearly evident in the last frame of Fig. 9b. All photographs show a vertical wavy line which is the result of the bow shock intersection with the free-jet boundary. This intersection is typical for all tests and does not affect the test section flow since it is at the perimeter of the free jet.

3.0 TEST DESCRIPTION

3.1 TEST CONDITIONS

A summary of the primary test conditions is given below.

M	PT, psia	TT*, °R	P, psia	T, °R	RE x 10^{-6}, ft^{-1}
3.94	17	719-1237	0.12	175	1.04
3.93	38	1063-1334	0.27	263	1.29
3.93	59	1536-1664	0.42	387	1.17
3.93	79	1663-1861	0.55	421	1.36
3.93	98	1854-1901	0.67	475	1.43

*PT was held constant while TT was increased over the range shown. Data were obtained at both ends and at selected intervals. Free-stream parameters shown above correspond to the lower TT value.

Tunnel circuit parameter data were obtained at each of these test conditions with model blockage at PT values of 60 psia and below. A test data summary is presented in Table 3 and a copy of the tunnel test log is given in Appendix C.

3.2 TEST PROCEDURES

3.2.1 General

The test operation was initiated by starting the tunnel at low pressure and temperature; stilling chamber pressure and temperature were then brought up slowly to provide time for monitoring critical pressure and temperatures to avoid possible hardware damage. Model blockage data were obtained at selected conditions. Dynamic pressure transducer data were recorded on analog tape at several test conditions.

3.2.2 Model Blockage Tests

In order to establish the effects of model blockage on the various pressures, data were recorded just prior to model injection. The model was then injected into the test section flow while recording shadowgraph movies. Shadowgraph sequence pictures were recorded at 2- to 4-sec intervals and pressure data were recorded after waiting sufficient time to allow for stabilization.

The shadowgraph system display was monitored continuously in an effort to visually confirm occurrence of flow breakdown (blockage). However, blockage was not visibly apparent during the test and confirmation was only obtained after the test by examination of the shadowgraph pictures, which showed blockage to be intermittent for the largest blunt model tested at total pressure up to 60 psia.

3.3 DATA REDUCTION

Free-stream test conditions were computed using the assumption of a real gas isentropic expansion from the stilling chamber to the test section. Mass flow rates through the Mach number 4 and Mach number 10 throats were computed from their respective stilling chamber conditions and throat area using the definition of flow rate for air through a sonic orifice:

$$\dot{m} = 0.532 \frac{PT}{\sqrt{TT}} \cdot AREA, \text{ lbm/sec}$$

PT ~ psia

TT ~ °R

AREA ~ orifice (throat) area, in.^{2}

Standard procedures were used for reduction of pressure and temperatures as sensed by the transducers and thermocouples, respectively.

3.4 DATA UNCERTAINTY

In general, instrumentation calibrations and data uncertainty estimates were made using methods (Ref. 4) recognized by the National Bureau of Standards (NBS). Measurement uncertainty is a combination of the bias and imprecision errors defined as:

$$U = \pm(B + t_{95}S)$$

where B is the bias limit, S is the sampled standard deviation and t_{95} is the 95th percentile point for the two-tailed Student's "t" distribution which for degrees of freedom greater than 30 is taken equal to 2.

Estimates of the measurement uncertainties for this test are given in Table 2. In general, measurement uncertainties are determined from in-place calibrations through the data acquisition system and the data reduction program.

The calibration of the dynamic transducers was evaluated in the VKF shock tube. With the transducer mounted perpendicular to the tube axis and 9 inches from the pressure tap, the response of the transducer was attenuated by about 50 percent. The frequency response of the installation was flat above 350 Hz. The estimated uncertainty cited in Table 2 reflects the performance of the transducer at atmospheric conditions without accounting for the presence of the tube installation. Evaluation of the uncertainty imposed by mounting these transducers perpendicular to the tube falls outside the scope of this document.

4.0 DATA PACKAGE

Sample tabulated data are presented in Appendix D. Those values deleted from the tabulations were either erroneous or not applicable when the data were obtained.

Based on an examination of the data it appears that several thermocouples in the mixing chamber were detached from the structure and were effectively measuring air temperature rather than structure temperature. The suspected thermocouples are TWC: 8, 9, 11.

Results presented in the data package show that all test objectives were achieved: (1) corebreaker effectively reduced mixing chamber pressure fluctuations by about a factor of five, (2) maximum allowable blunt model size is approximately 20 percent of the free-jet area, and (3) maximum operating temperature limit of 1900°R at PT = 100 psia can be achieved.

REFERENCES

1. Strike, W. T., Langford, J. M. and Davis, Lt. L. M."VKF Aerothermal Supersonic, Mach 4 Wind Tunnel Shakedown and Calibration," AEDC-TSR-81-V42, November 1981.

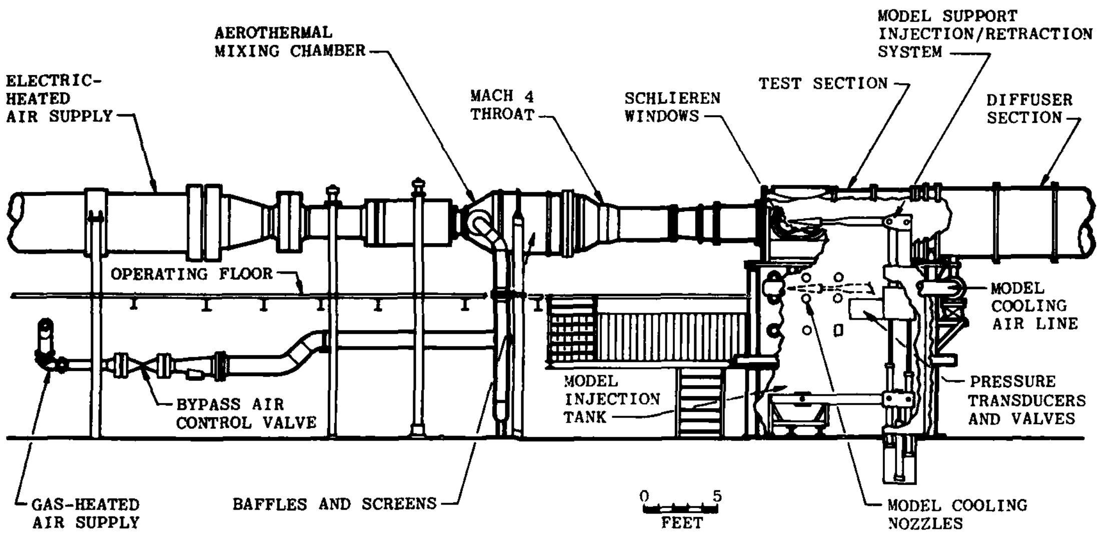
2. Strike, W. T. "Calibration and Performance of the AEDC - VKF Tunnel C, Mach 4 Aerothermal Wind Tunnel," AEDC-TR-82-6 (AD-A116279), May 1982.

3. Test Facilities Handbook (Eleventh Edition) "von Karman Gas Dynamics Facility, Vol. 3," Arnold Engineering Development Center, April 1981.

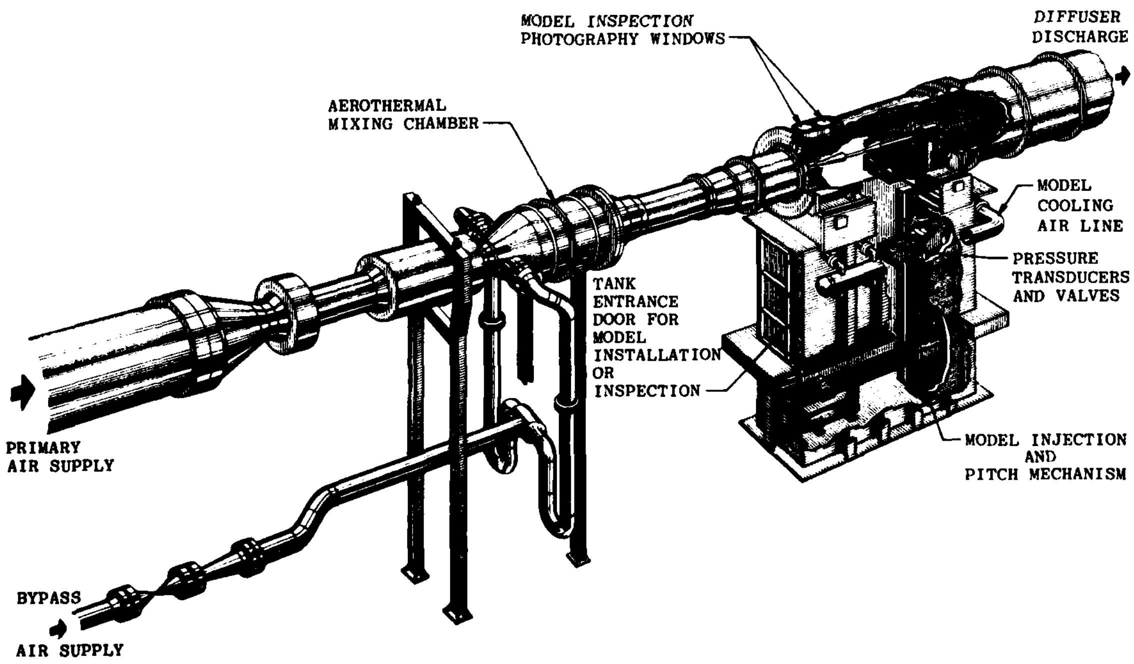
4. Thompson, J. W., Abernethy, R. B., et al. "Handbook Uncertainty in Gas Turbine Measurements," AEDC-TR-73-5 (AD-755356), February 1973.

APPENDIX A

ILLUSTRATIONS



a. Tunnel assembly



b. Perspective of tunnel test section area

Fig. 1 Tunnel C Mach 4.0 Configuration

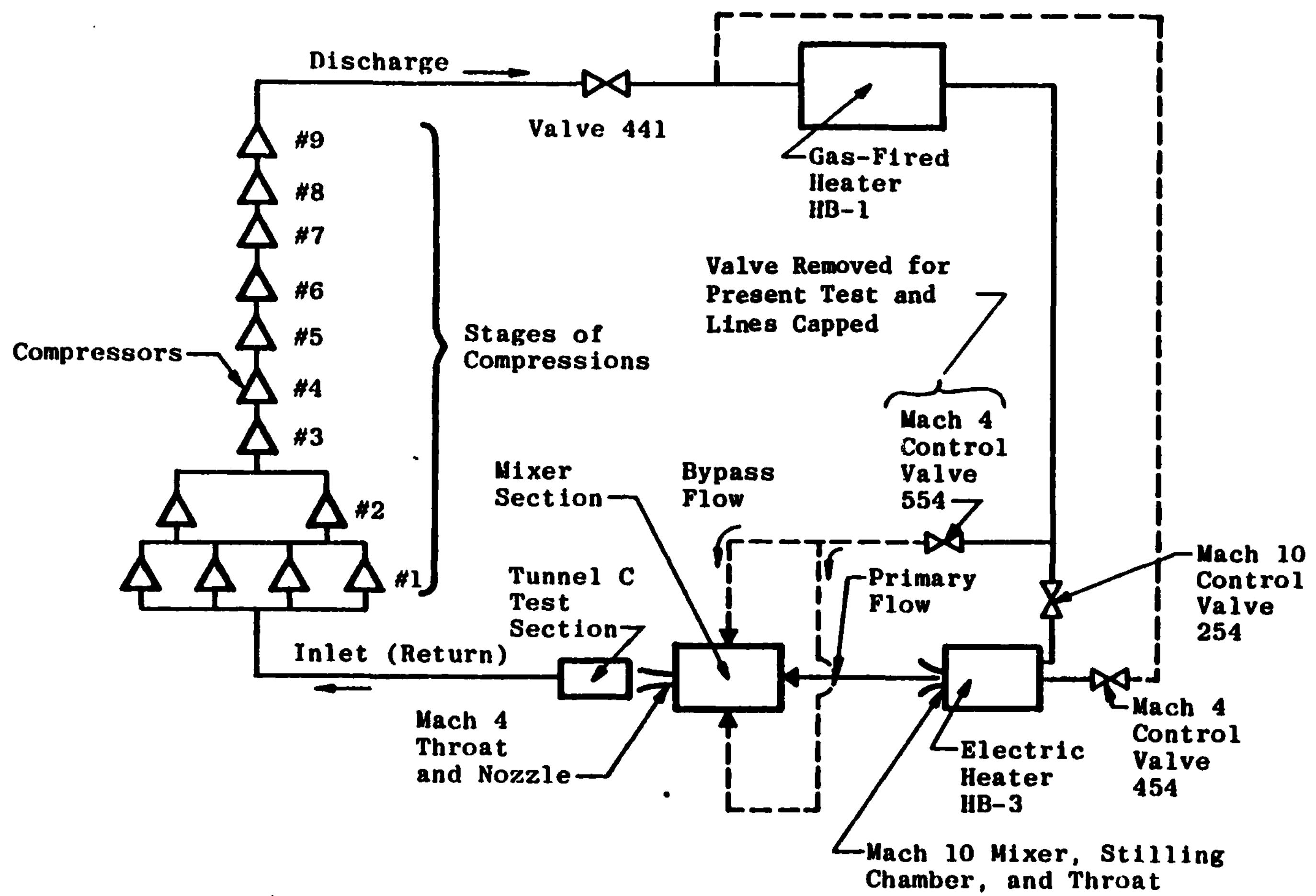
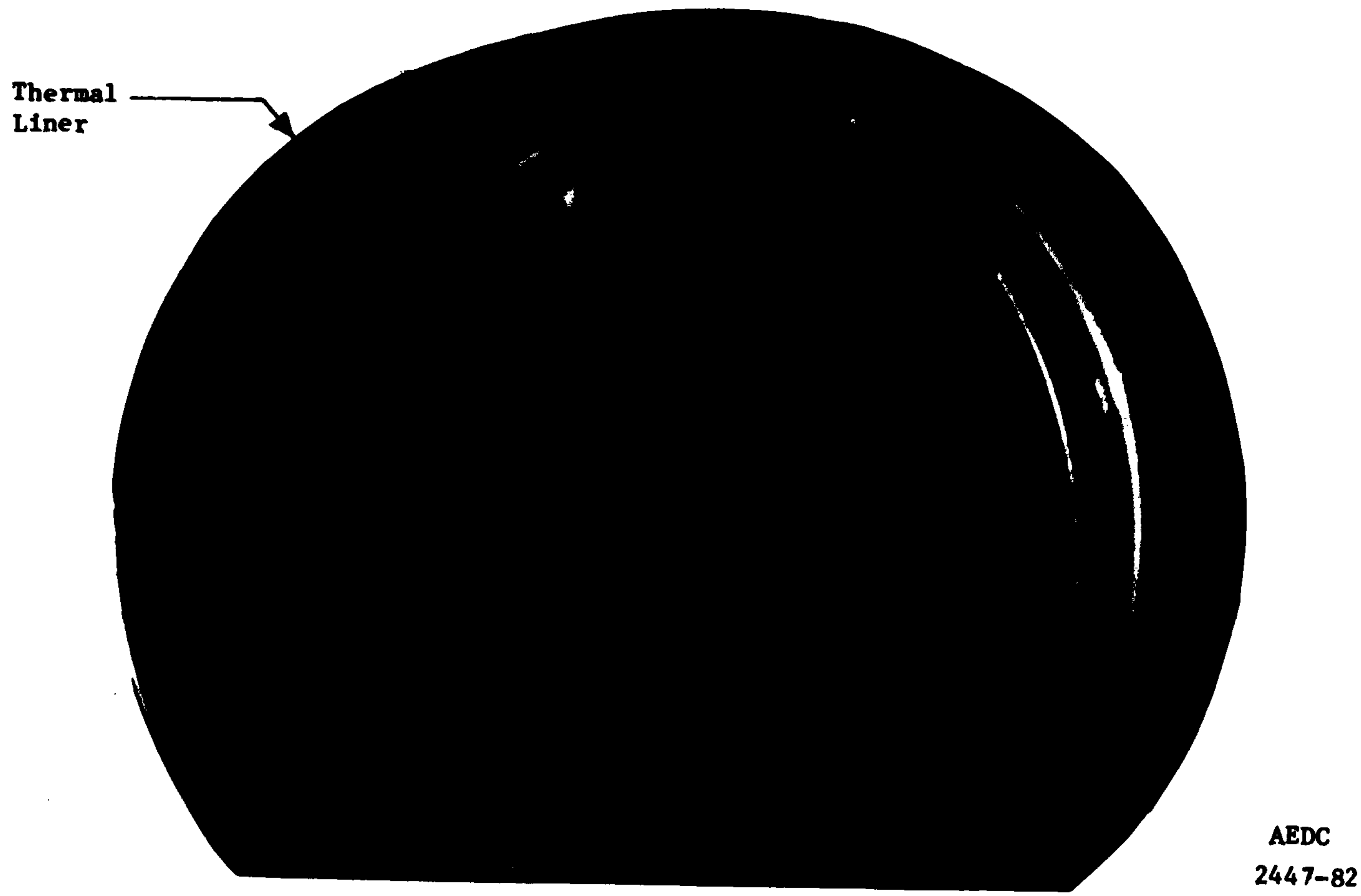
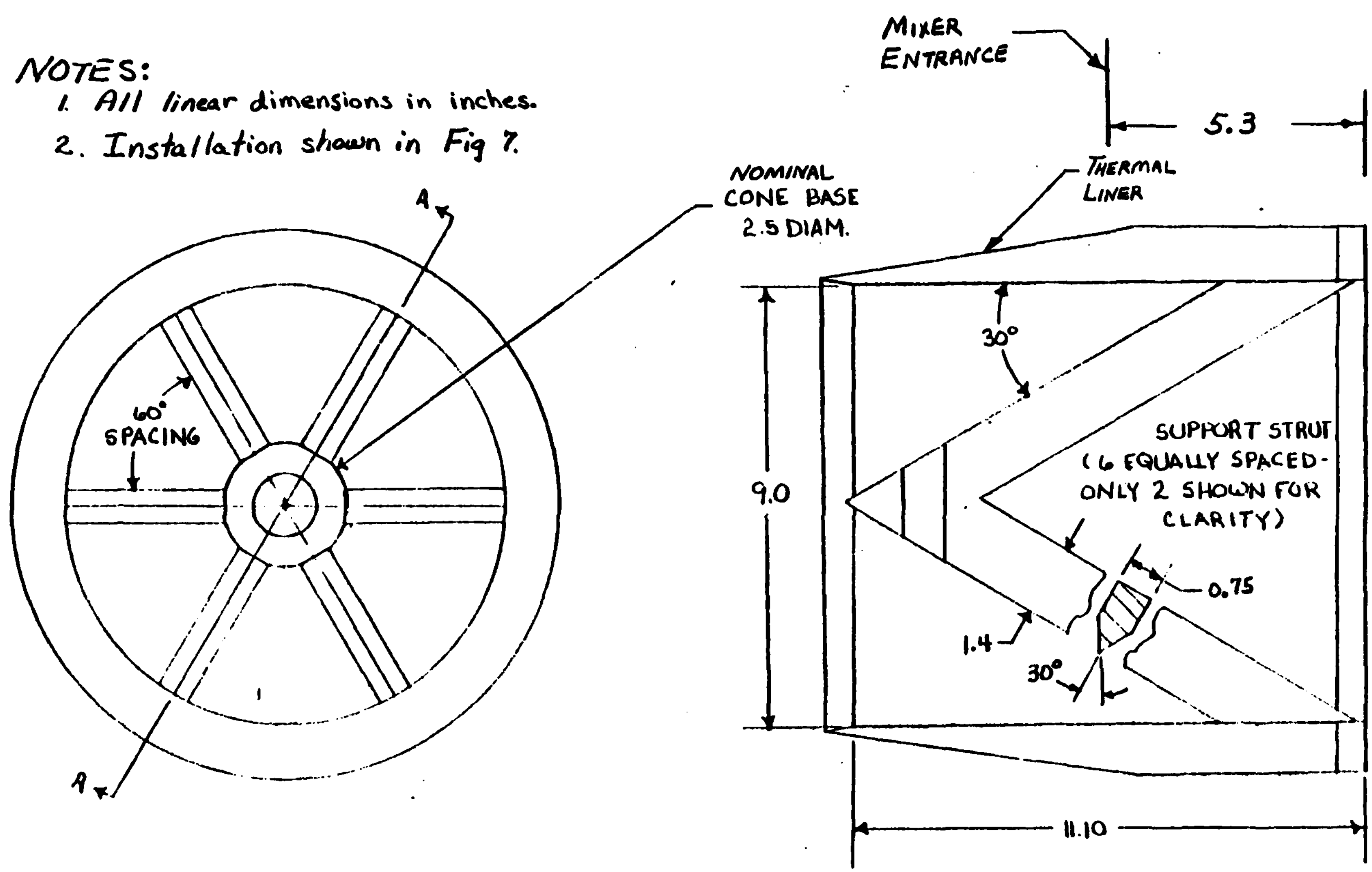


Figure 2. Mach 4 Aerothermal Wind Tunnel Series Heater Circuit

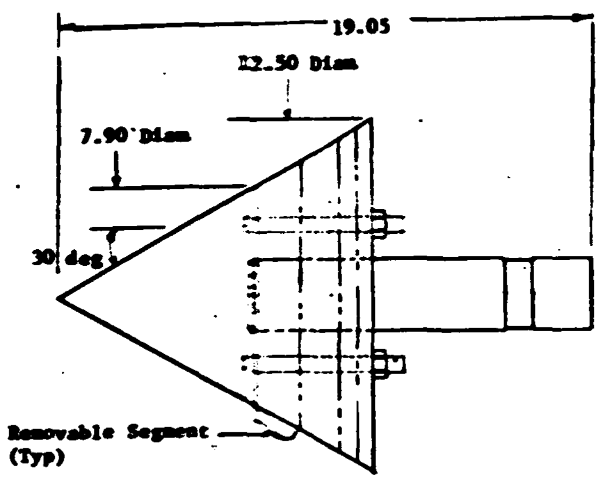


a. Installation Photograph - View Looking Downstream
Figure 3. Corebreaker

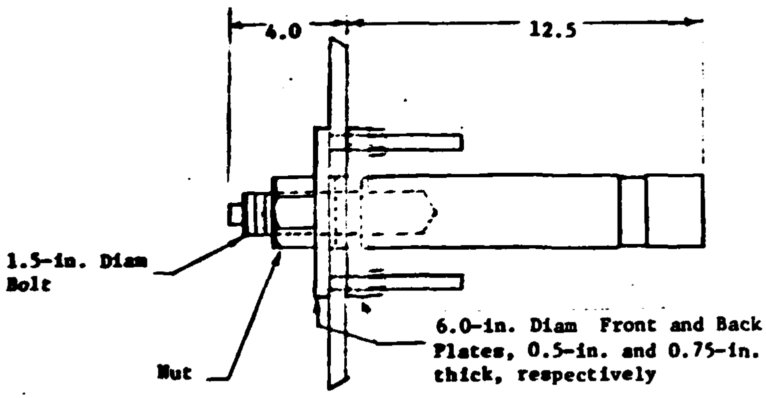


b. Corebreaker details

Figure 3. Concluded



a. Cone Models



b. Flat Face Models (12.5-in. Diam Shown)

NOTES:
1. All linear dimensions are inches.
2. Removable segments were split into halves, leaving ≈1/16-in. gap. Segments were assembled with gaps alternated by 90 deg.
3. Mild steel used for all parts.

CONFIG	MODEL	Diam, in.	A_M/A_T
1	12.50 Cone*	12.50	0.25
2	11.85 Cone	11.85	0.225
3	11.18 Cone	11.18	0.20
4	9.68 Cone	9.68	0.15
5	7.90 Cone	7.90	0.10
11	12.50 Flat*	12.50	0.25
12	11.85 Flat	11.85	0.225
13	11.18 Flat*	11.18	0.20
14	9.68 Flat*	9.68	0.15

* Models run

Figure 4. Blockage Models

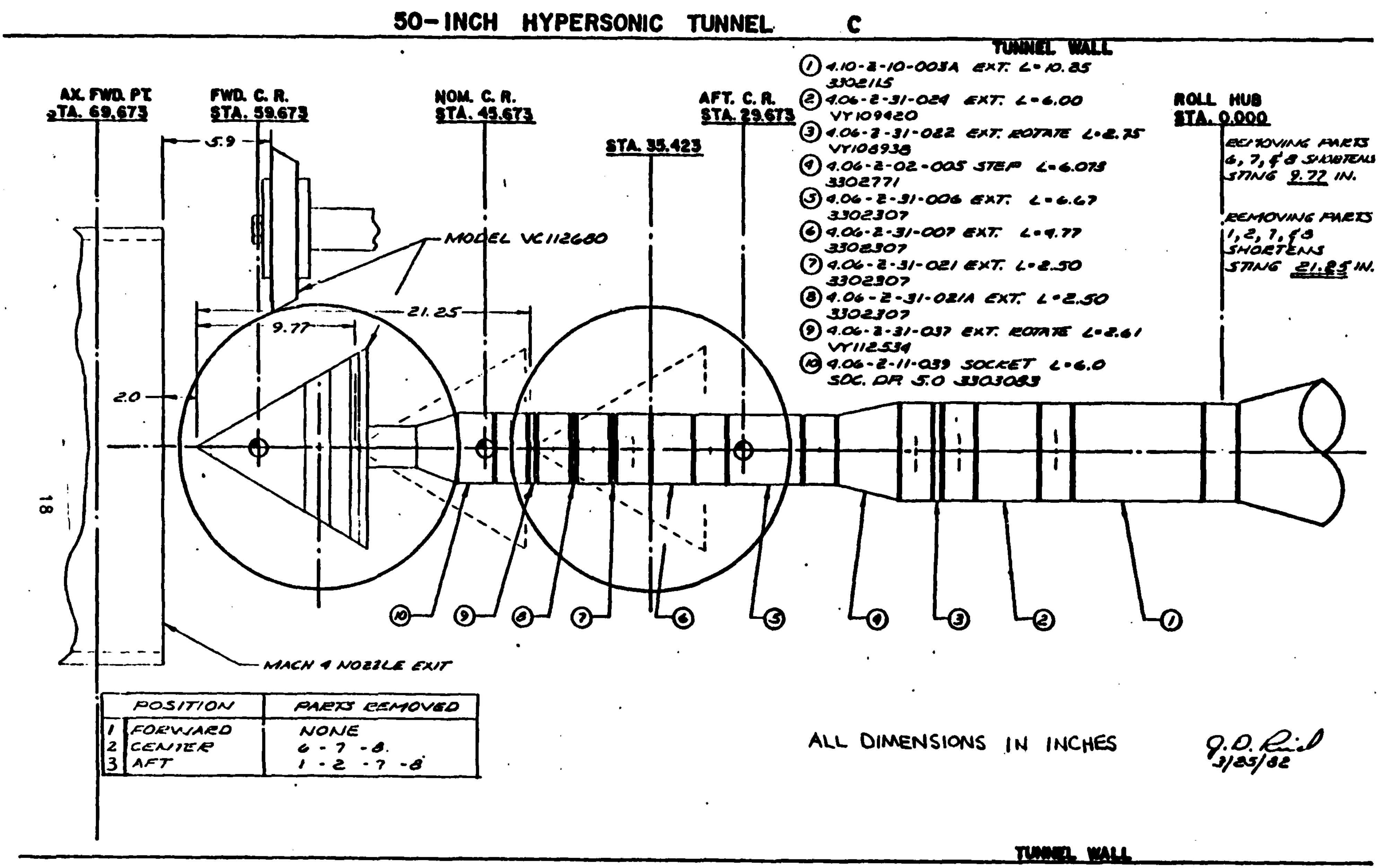
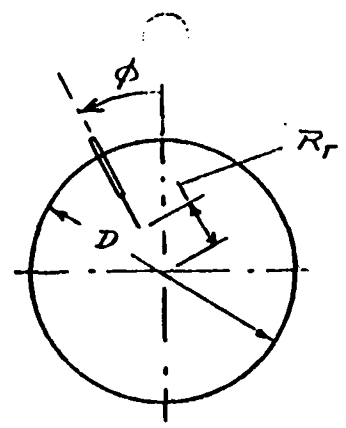


Figure 5. Blockage Model Installation Sketch



View Upstream
Toward HB-3

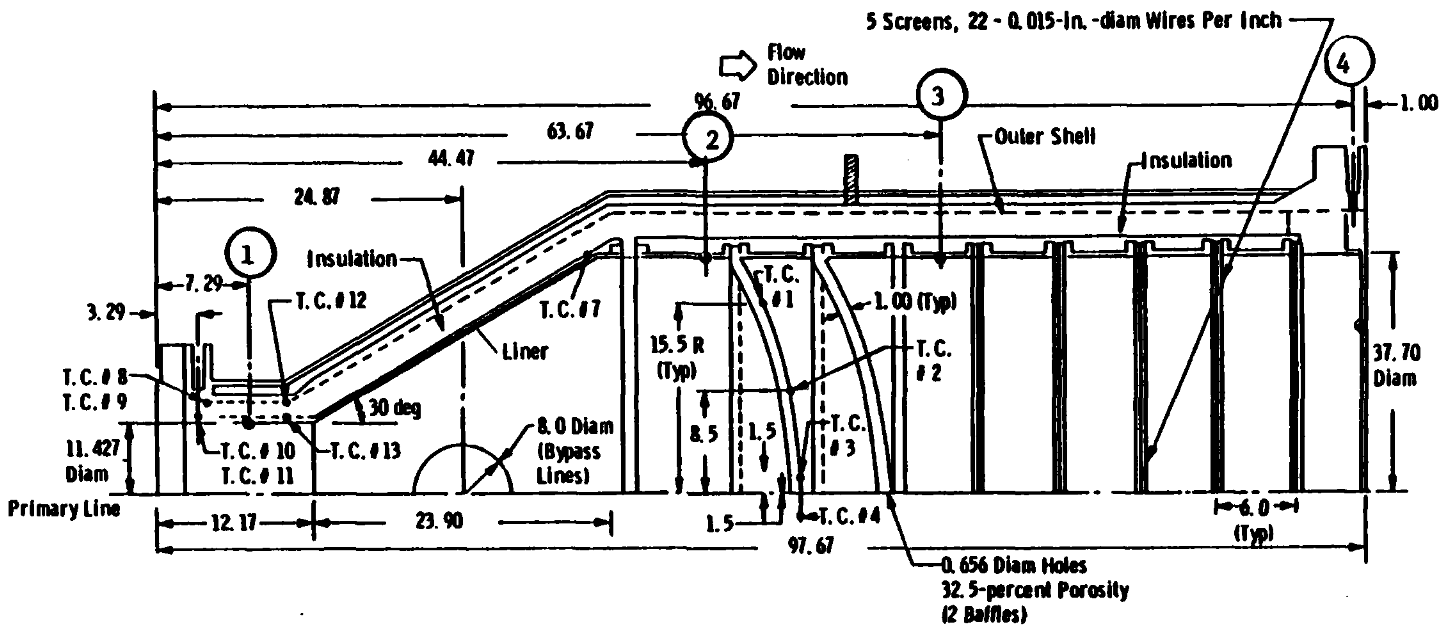
Mach-10 Stilling Chamber
Electric Heater (HB-3)
D = 12.0 in

PERMANENT LETTER CODE	TEST IDENTIFICATION	R_T, in	Φ, deg
D	TTC1	3.0	67.5
H	TTC2	2.0	157.5
K	TTC3	3.0	225.
M	TTC4	↓	270.
O	TTC5		315.
P	TTC6	2.0	337.5

Mach-4 Stilling Chamber
D = 37.7 in

	R_T, in	Φ, deg
TT1	16.5	15
TT2	9.5	60
TT3	0.5	90
TT4	9.5	150
TT5	16.5	195
TT6	9.5	240
TT7	4.5	285

Fig. 6. Total Temperature Probe Locations in the Stilling Chambers



Mixing Chamber Instrumentation

TWC	Thermocouple Location Position
1.	Baffle R = 15.5
2.	R = 8.5
3.	R = 1.5
4.	R = 1.5 (180 deg)
5.	R = 8.5 (180 deg)
6.	R = 15.5 (180 deg)
7.	Insulation/Liner
8.	Insulation/Outer Shell
9.	Insulation/Outer Shell (180 deg)
10.	Insulation/Liner
11.	Insulation/Liner (180 deg)
12.	Insulation/Outer Shell, Downstream Station
13.	Insulation/Liner, Downstream Station

Pressure Orifice	Axial Locations
1	7.29
2	44.47
3	63.67
4	96.67 (Stilling Chamber)

Note: T.C. Thermocouple

- Dynamic Pressure Measured at Each Location Using Ported Type Installation (DPWC1...DPWC4)
- Mean Differential Pressures Measured with Point 4 as Reference (PWC14, PWC24, PWC34)
- Absolute Pressure Measured at Point 4 (PWC4=PT)

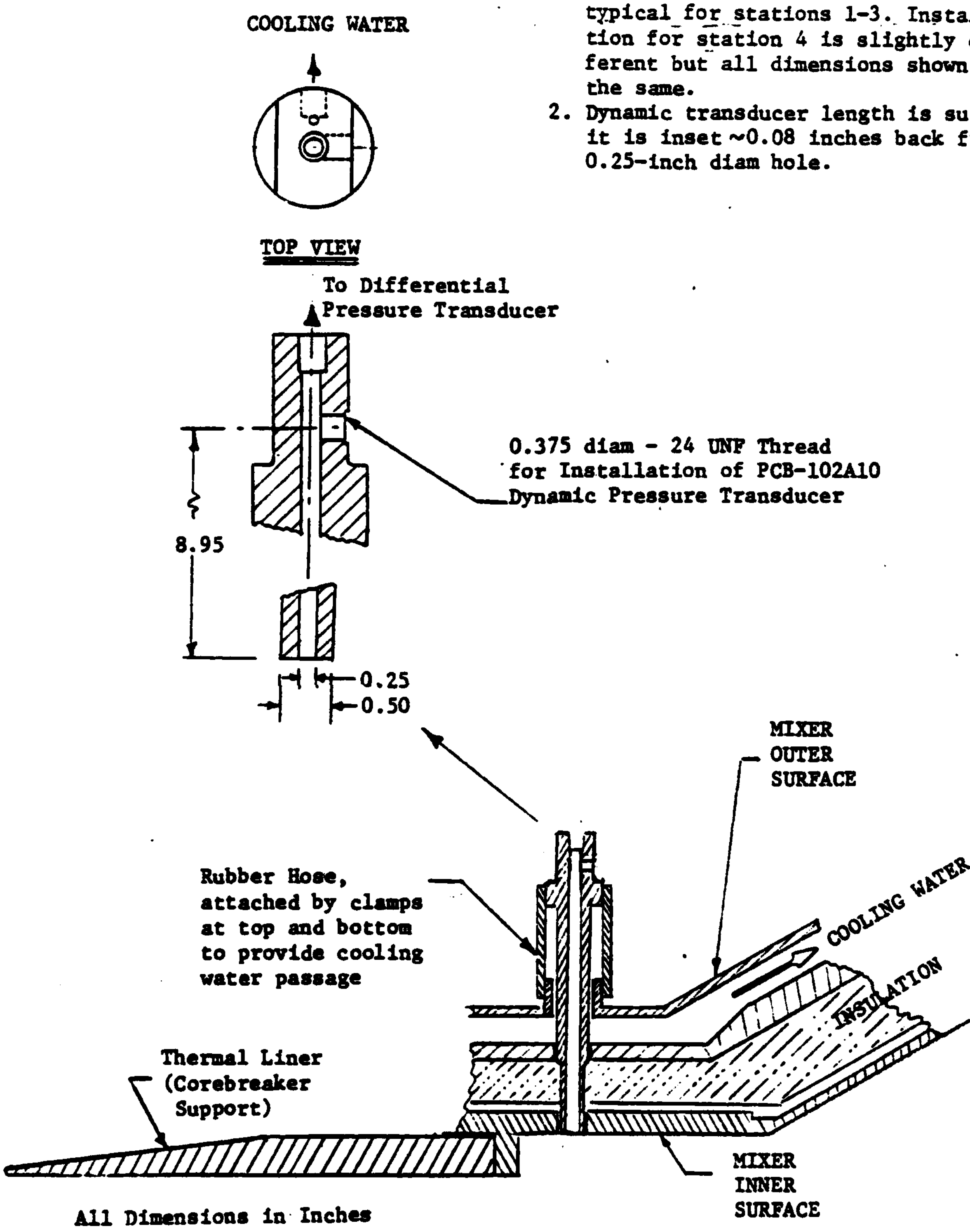
All Dimensions in Inches

a. General

Figure 7. Aerothermal Mixer Instrumentation Installation

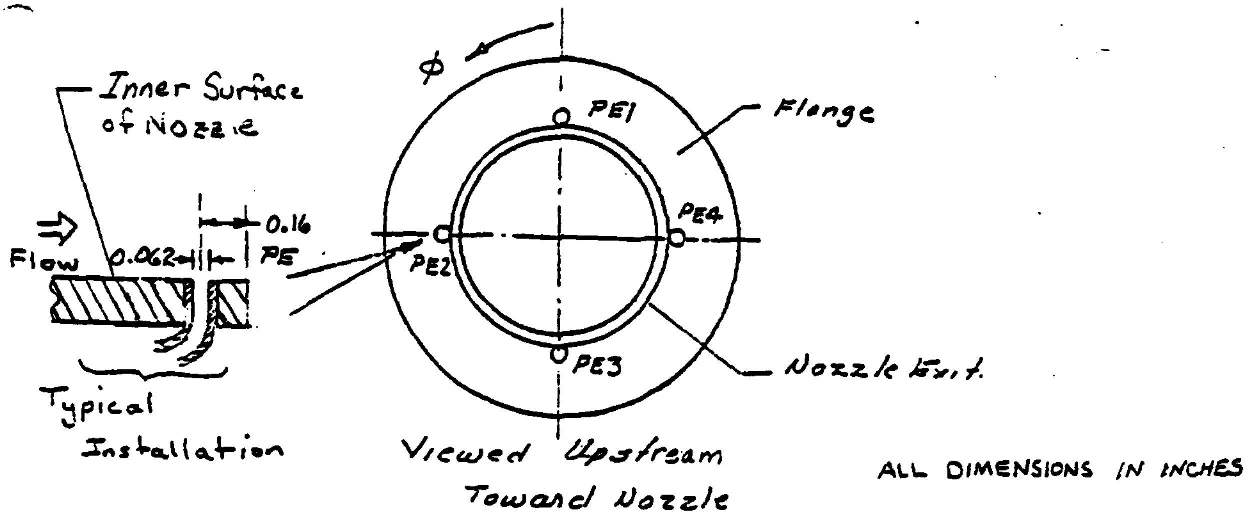
NOTES:

1. Installation shown for station 1, typical for stations 1-3. Installation for station 4 is slightly different but all dimensions shown are the same.
2. Dynamic transducer length is such that it is inset ~0.08 inches back from the 0.25-inch diam hole.



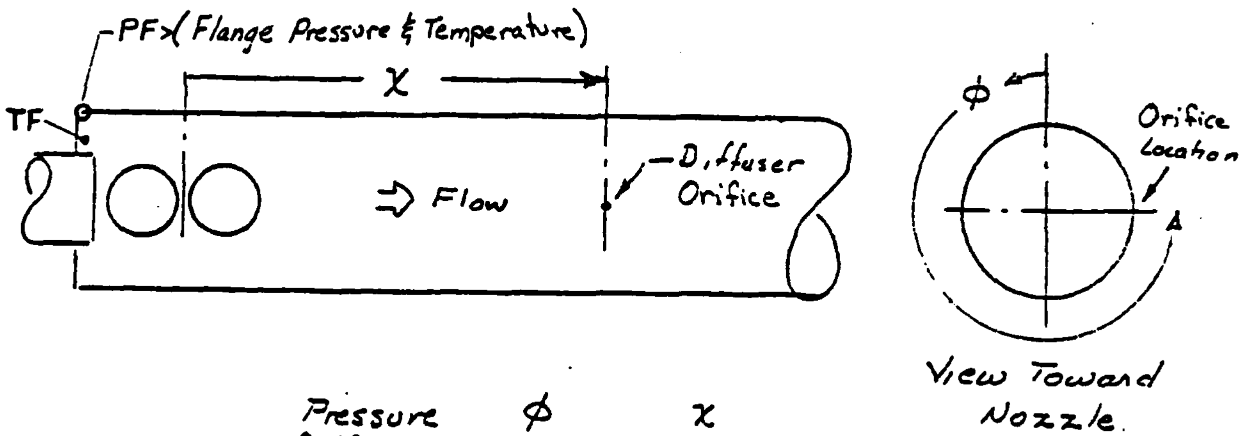
b. Typical Dynamic Pressure Transducer Installation

Figure 7. Concluded



Pressure Orifice	PE1	PE2	PE3	PE4
Radial Position, φ	0	90°	180°	270°

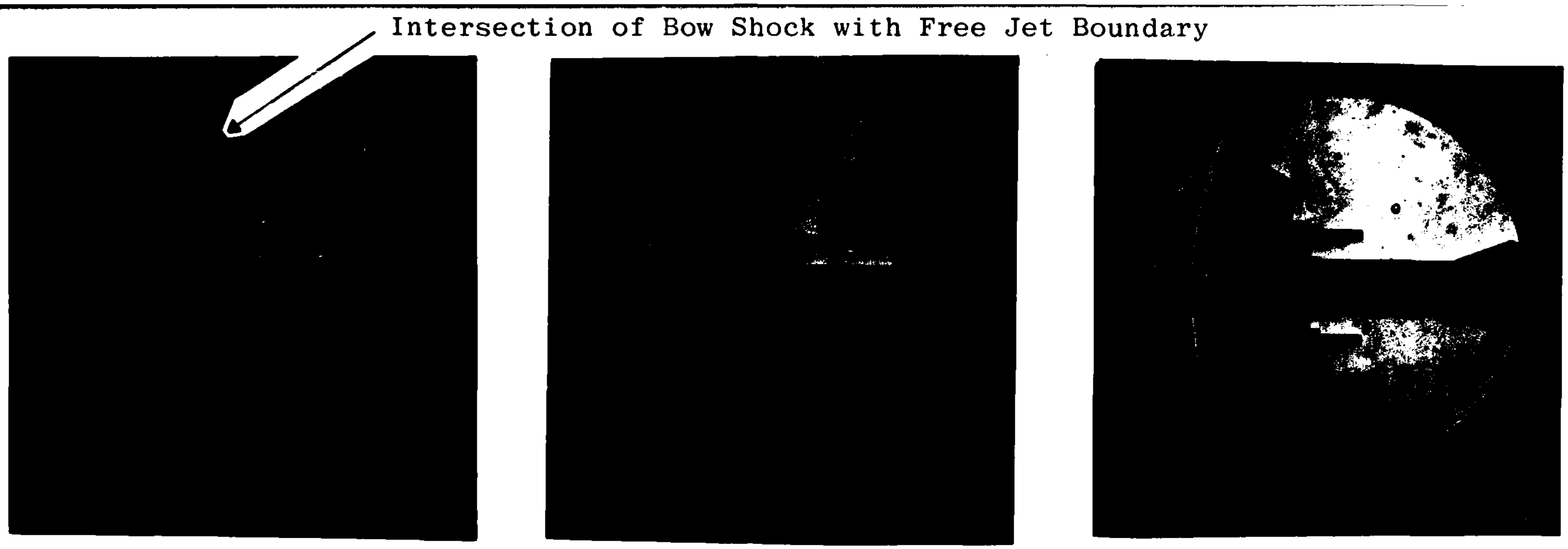
a. Nozzle Exit Instrumentation



Pressure Orifice	φ (deg)	X in	
PD1	270	152.25	Statics
PD2	↓	202.12	Statics
PD3	↓	252.25	Statics
PD4	↓	302.12	Statics
PD5	135	282.	Pitot Probe
PD6	90	1390.	(Downstream of Air Cooler)

b. Diffuser/Flange Instrumentation

Figure 8. Test Section and Diffuser Instrumentation



a. No Blockage - 11.18 in. Diam. Flat Face Model, RUN 8, PT = 39 psia

b. Intermittent Blockage - 12.5 in. Diam. Flat Face Model, RUN 7, PT = 39 psia

Figure 9. Shadowgraph Picture Sequence Illustrating Blockage

APPENDIX B

TABLES

TABLE 1. Data Transmittal Summary

The following items were transmitted to the Sponsor:

Lt. L. M. Davis and Lt. M. Swillum
AEDC/DOFO
Arnold AFS
TN 37389

Item	No. of Copies
Test Summary Report	2
Final Tabulated Data	2
Shadowgraphs	2
Installation Photographs	2

TABLE 2. ESTIMATED UNCERTAINTIES

a. Basic Measurements

Parameter Designation	STEADY-STATE ESTIMATED MEASUREMENT: Precision Index (S)			Bias (B)		Uncertainty $\pm(B + t_{95}S)$		Range	Type of Measuring Device	Type of Recording Device	Method of System Calibration
	Percent of Reading	Unit of Measurement	Degree of Freedom	Percent of Reading	Unit of Measurement	Percent of Reading	Unit of Measurement				
Temperatures, °F:		1	30		2		4	32 to 530	Chromel®-Alumel® Thermocouples	Doric Temperature Instrument/Digital Multiplexer	NBS Conformity Voltage Substitution Calibration
THB1, TT, TT_n		1		0.375		±(0.375% + 2)		530 to 2300			
TTC_n											
TD_n, TF, TPPKG,										Thermoplexer/Multiverter/RADS/Dec System 10	
TRF, TRH, TROLL,											
TSECTOR, TWC_n											
Absolute Pressures, psia:											
PHB1		0.40			2.00		2.80	<2000	Setra® Transducer	Analog to Digital (A/D) Converter into Digital Data Acquisition System (DDAS)	In-place calibration with secondary standard, multiple pressure levels applied
PT, PWC4		0.137			+		0.275	<250			
PTC		0.12			0.25		0.49	<156	Bell & Howell® Variable Capacitance Transducers		
		0.62			0.80		2.04	<500			
		0.62		0.16		±(0.16% + 1.24)		<2500			
Std. Pressure System Measurements:											
PB, PD_n, PE_n, PF		0.002		0.2		±(0.2% + 0.004)		<5	Baratron (MKS) Transducers; Wiancko Transducers		
Differential Pressures, psi:											
PWC_{i4}(i=1 to 3)		0.002	3		0.006		0.012	<5	Kulite Differential Pressure Transducer		
Dynamic Pressures:											
$DPWC_n$, psi analog tape values	(Resolution)	0.01	+	2 (Linearity)		2			PCB Piezotronics Dynamic Transducers	Bell & Howell Model 3700B Mag Tape Recorder	Mfg. Atmos. calib. and shock tube subatmos. calibration
RMS meter, mv	0.5		+		+	1		<1000	AEDC Assembled Intronics Modules	A/D converter into DDAS	Compared to Fluke® True RMS Voltmeter

TABLE 2. Concluded

b. Calculated Parameters

Parameter Designation	STEADY-STATE ESTIMATED MEASUREMENT							Condition
	Precision Index (S)			Bias (B)		Uncertainty $\pm(B + t_{95}S)$		
	Percent of Reading	Unit of Measurement	Degree of Freedom	Percent of Reading	Unit of Measurement	Percent of Reading	Unit of Measurement	
MACH	0.38**					0.76		1
	0.38**					0.76		2
P	2.02			0		4.04		1
	2.17			0		4.34		2
T	0.58			0.28		1.44		1
	0.64			0.28		1.56		2
V	0.10			0.14		0.34		1
	0.17			0.14		0.48		2
PT2	1.28			0		2.56		1
	1.51			0		3.02		2
RE	0.90			0.37		2.17		1
	1.19			0.42		2.38		2

**Determined from tunnel test section repeatability and uniformity during tunnel calibrations.

Note: Condition 1: PT = 98 psia, TT = 1901°R
Condition 2: PT = 17 psia, TT = 719°R

TABLE 3. Test Data Summary

a. Blockage Data

MODEL	* POSITION	Nominal PT,psia 17	38	58
		RUN NUMBERS		
12.5 Cone	1 (FWD)	3(2)	12(11)	
12.5 Flat		5(4)	7(6)	15(14)
11.18 Flat			8(6)	
9.68 Flat			10(9)	
12.5 Flat	2(Center)	28,29(27)	26(25)	

Note: RUN numbers in ( ) are appropriate reference runs, without model in the tunnel.

*Position relative to nozzle exit shown in Fig. 5

b. Dynamic Pressure Transducer - Analog Tape Records

Nominal PT,psia	RUN Numbers
17	3
39	7,8
58	15
79	16,19
98	21

APPENDIX C
VKF TUNNEL C MACH 4.0 TEST LOG

VKF TUNNEL C MACH 4.0 TEST LOG

USER	PROJECT TITLE	PROJECT	DATE
AEDC / DOFO Lt. Larry Davis, Lt. Mary Swillom	AEDC Aerothermal Validation – Core Breaker and Blockage	C115VC (V--C-10)	APRIL 7, 1982
REPRESENTATIVE(S)	MODEL: Blunt & Conical Blockage	TEST PERSONNEL: D. Carver, W. Strike, D. Akers, G. Gillis, O. Dunkln, W. Brown, J. Willis	

Run	Configuration Code	Config. Confirmed	M	PT psia	TT °F	Position	Dynamic Transducer Gains		Analog Tape Data			Time	Remarks
8001	—	—	4.0	2.3	—	—	2233					00:35	Check Data – No Flow
1	0	DBC		16	127	1						00:50	Omit from final data
2	0			17	259							1:10	
3	1	DBC		17	269				*			1:11	
4	0			17	433							1:36	
5	11	DBC		17	452							1:39	
6	0			38	603		1222					1:50	
7	11	DBC		39	617				*			1:50	
8	13	DBC		39	721				*			2:02	
9	0			39	783							2:13	
10	14	DBC		38	792							2:16	
11	0			38	845							2:28	Relief Valve Caused
12	1	DBC		39	874							2:29	Emergency Shut Down
13	0			43	998							3:47	
14	0			58	1201							3:58	
15	11	DBC		58	1204				*			4:00	
16	0			79	1203	2			*			4:15	
17	0			78	1277							4:25	
18	0			78	1301							4:31	
19	0			79	1351				*			4:41	

NOMENCLATURE

POSITION
1 Forward
2 Center
3 Aft

Configuration
1 ~12.5 CONE
11 ~12.5 FLAT
13 ~11.18 FLAT
14 ~9.68 FLAT
0 ~ NONE

DYNAMIC TRANSDUCER GAINS

CODE	GAIN
1	1
2	10
3	100

ANALOG TAPE DATA
* Denotes data recorded

VKF TUNNEL C MACH 4.0 **TEST LOG**

PAGE	2	OF	2

USER	PROJECT TITLE	PROJECT	DATE
AEDC/DOFO	AEDC Aerothermal Validation - Core Breaker and Blockage	C115VC (V--C-10)	APRIL 7, 1982
REPRESENTATIVE(S): Lt. Larry Davis, Lt. Mary Swillum	MODEL: Blunt & Conical Blockage	TEST PERSONNEL: D. Carver, W. Strike, D. Akers, G. Gillis, O. Dunkin, W. Brown, J. Willis	

Run	Configuration Code	Config. Confirmed	M	PT psia	TT °F	Position	Dynamic Transducer Gains		Analog Tape Data			Time	Remarks
20	0		4.0	79	1401	2	1222					0503	
21				98	1394				*			0514	
22				97	1395							0525	
23				98	1441							05:31	
24				59	1076							0548	
25				39	863							0554	
26	11	DBC		39	833		2222					0556	
27	0			19	793							0558	
28	11	DBC		19	789							0559	
29	11	DBC		17	777							0603	Recorded several points and observed loss of flow as pressure was decreased slowly from PT = 17.

NOMENCLATURE

POSITION	
1	Forward
2	Center
3	Aft

Configuration

1 ~12.5 CONE	14 ~ 9.68 FLAT
11 ~12.5 FLAT	0 ~ NONE
13 ~11.18 FLAT	

DYNAMIC TRANSDUCER GAINS

CODE	GAIN
1	1
2	10
3	100

ANALOG TAPE DATA

* Denotes data recorded

APPENDIX D

SAMPLE TABULATED DATA

ARVIN/CALSPAN FIELD SERVICES,INC.
AEDC DIVISION
VON KARMAN GAS DYNAMICS FACILITY
ARNOLD AIR FORCE STATION, TENN
AEDC - VKF AEROTHERMAL VALIDATION - CORE BREAKER AND BLOCKAGE

DATE COMPUTED 7-MAY-82
DATE RECORDED 7-APR-82
TIME RECORDED 11 9:58
TIME COMPUTED 08:56
AF PROJECT NO. C115-VA

DATA TYPE 1 : TUNNEL CIRCUIT PARAMETERS

FLOW	HEATER	VALVE	PERCENT	PRESSURE (PSIA)	TEMPERATURE (DEG-R)	MASS FLOW (LBM/SEC)	MFRAC	DEWPT DEG-F	AREA (IN2)	PHB1 (PSIA)	THB1 (DEGR)
PRIMARY	HB-3	V254	100	317.6	754.	14.73	1.00		2.39	351.	872.
BY-PASS	HB-1	V554	0								
MACH 4				16.8	719.	14.72	1.000	-19.0	44.14		

**** TEMPERATURES (DEG-R) ****

BY-PASS DUCTING	TD1 542.	TD2 566.	TD3 530.				
HB-3 HEATER	TTC1 (D) 754.	TTC2 (H) 754.	TTC3 (K) 754.	TTC4 (M) 750.	TTC5 (O) 753.	TTC6 (P) 754.	
MIXING CHAMBER BAFFLE	TWC1(15.5) 719.	TWC2(8.5) 710.	TWC3(1.5) 720.	TWC4(-1.5)	TWC5(-8.5)	TWC6(-15.5) 733.	
INSULATION/LINER/OUTERSHELL	TWC7-I/L 684.	TWC8-I/OS 645.	TWC9-I/OS 599.	TWC10-I/L 582.	TWC11-I/L 630.	TWC12-I/OS 551.	TWC13-I/L 679.
STILLING CHAMBER	TT1 (16.5, 15) 713.	TT2 (9.5, 60) 722.	TT3 (0.5, 90) 724.	TT4 (9.5,150) 721.	TT5 (16.5,195) 713.	TT6 (9.5,240) 722.	TT7 (4.5,285) 720.
FLANGE/ VALVE/ THROAT	TF 514.	TV1 524.	TV2 523.	TRF 523.	TRH 523.		
TUNNEL MECH	TSECTOR 518.	TROLL 511.	TPPKG 516.				

TEST CONDITIONS RUN NO. 2

MACH =	3.942		P =	0.120	PSIA		CONFIG	MODEL	POSITION
PT =	16.8	PSIA	T =	175.2	DEGR		0	NONE	1
TT =	719.	DEG-R	RHO =	5.730E-05	SLUG/FT3				
Q =	1.30	PSIA	V =	2.558E+03	FT/SEC				
RE =	1.040E+06	PER/FT	MU =	1.410E-07	LBF-SEC/FT2				
			PT2 =	2.45	PSIA				

PAGE NO. 1

ARVIN/CALSPAN FIELD SERVICES, INC.
AEDC DIVISION
VON KARMAN GAS DYNAMICS FACILITY
ARNOLD AIR FORCE STATION, TENN
AEDC - VKF AEROTHERMAL VALIDATION - CORE BREAKER AND BLOCKAGE

DATE COMPUTED	7-MAY-82
DATE RECORDED	7-APR-82
TIME RECORDED	1: 9158
TIME COMPUTED	08:56
AF PROJECT NO.	C115-VA

DATA TYPE 1 : TUNNEL CIRCUIT PARAMETERS

FLOW	HEATER	VALVE	PERCENT	PRESSURE (PSIA)	TEMPERATURE (DEG-R)	MASS FLOW (LBM/SEC)	MFRAC	DEWPT DEG-F	AREA (IN2)	PHB1 (PSIA)	THB1 (DEGR)
PRIMARY	HB-3	V254	100	317.6	754.	14.73	1.00		2.39	351.	872.
BY-PASS	HB-1	V554	0								
MACH 4				16.8	719.	14.72	1.000	-19.0	44.14		

*** PRESSURES (PSIA,PSI,MV) ****

HB-3 HEATER
PTC1(PSIA)	PTC2(PSIA)
317.6	315.1

MIXING CHAMBER
				TOTAL	BAF+SCR	SCREENS	BAFFLES
PWC1(PSIA)	PWC2(PSIA)	PWC3(PSIA)	PWC4(PSIA)	PWC14(PSI)	PWC24(PSI)	PWC34(PSI)	PWC23(PSI)
13.82	17.04	16.90	16.82	-3.00	0.23	0.08	0.14
DPWC1(MV)	DPWC2(MV)	DPWC3(MV)	DPWC4(MV)				
41.93	11.17	4.99	4.79				
DPWC1(PSI)	DPWC2(PSI)	DPWC3(PSI)	DPWC4(PSI)				
1.02	0.26	0.11	0.10				
CP1	CP2	CP3	CP4				
7.357E-02	1.535E-02	6.668E-03	5.782E-03				

STILLING CHAMBER
PTP(PSIA)	REDUNDANT PTP(PSIA)
16.82	16.73

TEST SECTION
PE1(0)	PE2(90)	PE3(180)	PE4(270)	PF(PSIA)	PEAVG(PSIA)	PF/PEAVG
0.121	0.123	0.122	0.134	0.035	0.125	0.277

DIFFUSER
PD1(152)	PD2(202)	PD3(252)	PD4(302)	PD5(282)	PD6(1390)	PB	PB/PTP
0.051	0.063	0.116	0.173	0.746	0.418	0.097	0.006

TEST CONDITIONS RUN NO. 2

MACH =	3.942		P =	0.120	PSIA	
PT =	16.8	PSIA	T =	175.2	DEGR	
TT =	719.	DEG-R	RHO =	5.730E-05	SLUG/FT3	
Q =	1.30	PSIA	V =	2.558E+03	FT/SEC	
RE =	1.040E+06	PER/FT	MU =	1.410E-07	LBF-SEC/FT2	
			PT2 =	2.45	PSIA	

CONFIG	MODEL	POSITION
0	NONE	1

PAGE NO. 2